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A Full-Duplex PON with Hybrid 64/16/4QAM OFDM Downlink and Hybrid 16/8/QPSK OFDM Uplink

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Abstract

In the context of next-generation optical access networks beyond 10 G, for high SE and flexible dynamic bandwidth allocation (DBA), the scheme of hybrid 64/16/4QAM-OFDM signal for downlink transmission and hybrid 16/8/QPSK-OFDM signal for uplink transmission is successfully proposed and experimentally presented in a full-duplex PON based on OFDM system. Here, for the uplink, in order to unit management of the optical line terminal (OLT) and reduce cost, the optical source functioned as the optical subcarrier at optical network units (ONUs) is from OLT in the central station. Moreover, there is an external cavity laser (ECL) with center frequency of 193.2 THz not only employed as optical modulated signal but also acted as LO signal. Our simulation results show that bit error ratio (BER) under hardware detection forward error correction has been successfully gained after 20 km of SSMF transmission. It is observed that the receiver sensitivity of multilevel PSK (M-PSK) is obviously larger than that of the M-QAM in this measurement scheme.

Keywords

Passive Optical Network, Digital Signal Processing, Full-Duplex, Hybrid Modulation, Orthogonal Frequency Division Multiplexing

1. Introduction

Over the past decades, for both developing wider, faster, and smarter access network and providing subscribers with best services experience, such as internet protocol television (IPTV), high definition television (HDTV), video-on-demand (VOD), virtual private network (VPN), cable television (CATV), and surfing the Internet, passive optical network (PON) has been successfully proposed and experimentally demonstrated for the next generation broadband optical access system [1]. To meet the ever-increasing bandwidth requirements of the further future optical access systems, a large number of PON architectures have been successively introduced and presented. Firstly, time division multiplexing PON (TDM-PON) such as broadband PON (BPON), Ethernet PON (EPON) and gigabit PON (GPON), which is the most significant energy efficiency optical access method currently deployed in fiber-to-the-x (HTTx), connects the optical line terminal (OLT) with the multi-optical network units (ONUs) with the help of the optical distribution network(ODN) in the form of point-to-multipoint [2].

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Furthermore, wavelength division multiplexing PON (WDM-PON) is another scheme having been widely investigated because of high bandwidth and low latency, where the passive splitter has been replaced by arrayed waveguide gratings (AWG) [3]. Consequently, hybrid PON (HPON) such as time and wavelength PON (TWDM-PON), which can be emerged as a primary solution for the next generation passive optical stage 2(NG-PON2) by the full service access network (FSAN) community in the April 2012, stacking multiple pairs of wavelengths into XG-PONs [4]. Then, frequency division multiplexing PON (FDM-PON) is pretty different from OFDM-PON, which has also been explored for access networks, with low computational complexity and peak-to-average power (PAPR) reduction [5] [6]. Specifically, for the sake of transmission capacity enhancement of high speed optical systems and networks, the transmission of mode division multiplexing-based PON (MDM-PON) system over few-mode fiber (FMF) is discussed, in which modal crosstalk is one of the most critical issues [7].

Recently, orthogonal frequency division multiplexing (OFDM) scheme regarded as a multicarrier modulation (MCM) technique has been widely considered as a very promising candidate for either wireless communication in 1909 or optical fiber communication (OFC) in 2009 owing in large part to high spectral efficiency, flexible dynamic bandwidth allocation, outstanding tolerance against chromatic dispersion (CD) and polarization mode dispersion (PMD), evident improvement of the transmission rate, simple channel equalization, and high-level modulation format [8]-[13]. In order to counteract the dispersion of OFC posed by larger transmission capacity, PON combined with OFDM scheme has been widely used in broadband access "last mile" [9]. For physical layer security enhancement and PAPR reduction, varies techniques based on chaotic scheme have been described in OFDM-PON system, including chaos IQ-encryption-based optimal frame transmission (IQ-OFT) technique [10], and analog-digital hybrid chaotic system [11]. An OLT receiver based on both an optical coherent detection and a fixed-gain front-end electrical amplifier in OFDM/TDMA-PON system was investigated, which was able to normalize the power of the upstream burst OFDM signal [12]. R. B. Nunes *et al.* demonstrated the SE of the bandwidth scalable OFDM PON (BSOFDM-PON) system with subcarrier emphasis was enabled by advanced modulation format and simple channel compensation [13].

In this paper, we successfully analyzed a full-duplex PON access technique for both high SE and flexible dynamic bandwidth allocation in in-phase/quadrature-phase modulation coherent detection OFDM (IQ-CO-OFDM) system, which consisted of two 40-Gb/s links signal transmitted over 20-km optical fiber path of SMF-28. One is hybrid 64/16/4QAM OFDM signal used for the downlink transmission and the other is hybrid 16/8/QPSK OFDM signal available for the uplink transmission. For the sake of cost effective and complexity reduction, an ECL at 193.2THz has been successfully found for both downlink to provide an optical carrier signal with the ONU and uplink to perfectly generate LO signal. It is necessary for us to study how to realize subcarrier allocation in IFFT/FFT based on passive optical access system.

2. Principle of Hybrid Modulation

As we know, PON is of great importance in optical access network, which concluding none electrical component and electronic power supply in optical distribution network (ODN). As **Figure 1** shows that point to multi points (P2MP) has been a promising candidate for the PON among a large number of schemes, in which, the front end devices functioned OLT communicate with a few customer premise equipment (CPE) proposed of ONUs/ONTs by passive optical cable with SSMF and passive power splitter/coupler (PPSC).The situation of free-source in the ODN can avoid electromagnetic interference stemming from external devices, decrease failure rate between line and device , promote system reliability , and cut down maintenance cost in the next generation passive optical network.

The basic OFDM modulation and demodulation principle based on hybrid 64/16/4-QAM signal and hybrid 16/8/Q-PSK signal can be depicted in **Figure 2** in detail, in which, the inset stands for the block design of subcarrier allocation for hybrid modulation technology. More specifically, among all the 128 subcarriers, namely, the number of IFFT/FFT are 128, 120 subcarriers are efficiently transmitted useful data, others 8 subcarriers are automatically set to zero. For reference, subcarriers arranging from 5 to 44, from 45 to 84, and from 85 to 124 are simultaneously allocated to 4QAM, 16QAM, and 64QAM, respectively, while, the same location subcarriers are assigned to QPSK, 8PSK, and 16PSK, respectively. However, channel estimation and synchronization technique has been widely applied in OFDM receiver end to efficiently resist multipath fading imposed by inter-carrier interference (ICI) and inter-symbol interference (ISI), where the situation is the same as that the optical signal based on OFDM (OOFDM) can contradict dispersion in the fiber channel.

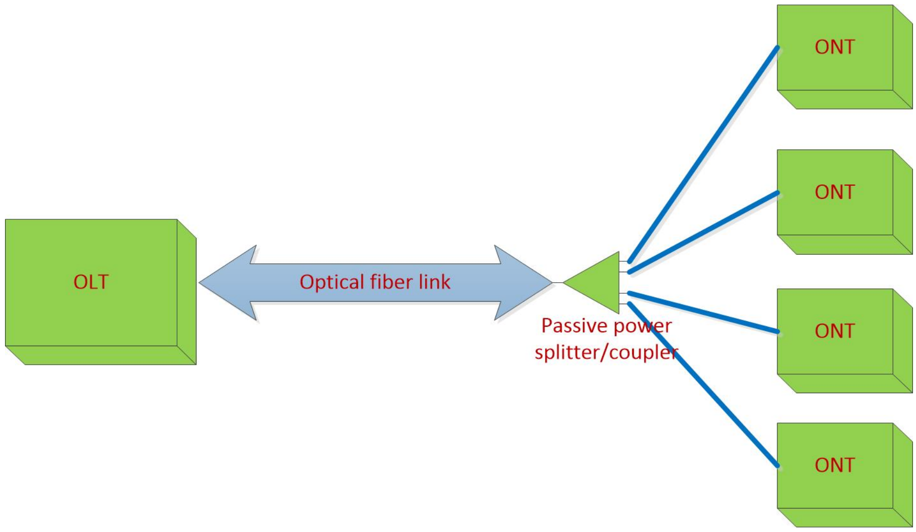


Figure 1. Block diagram of broadband optical access system.

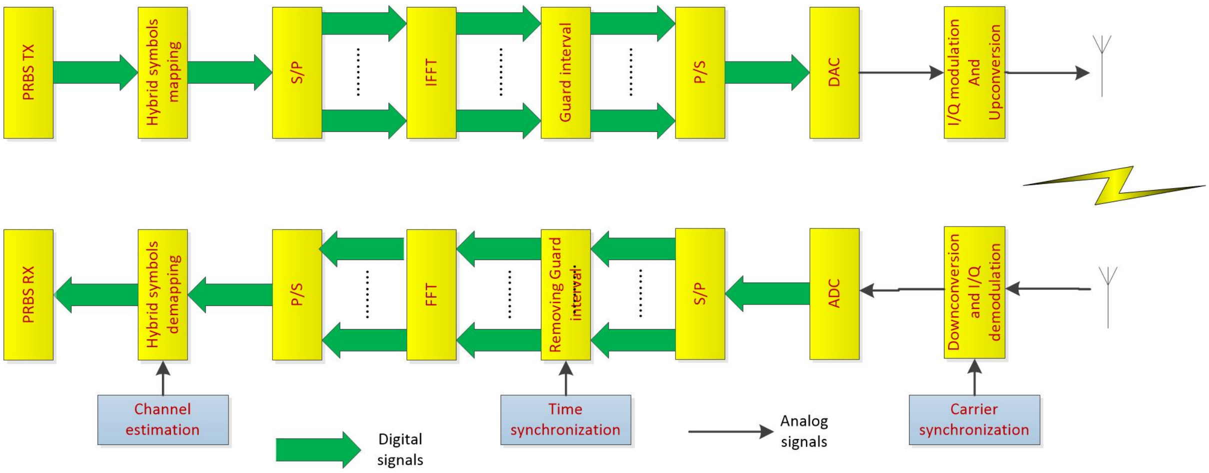


Figure 2. Block diagram of OFDM transceiver.

3. System Simulation for 40 Gb/s Hybrid OFDM-PON

The simulation setup of the full-duplex OFDM-PON for both hybrid 64/16/4QAM OFDM downlink signal and hybrid 16/8/QPSK signal transmission is shown in **Figure 3**. For downlink transmission part, at the central station (CS), the continuous wavelength (CW) light-wave functioning as the optical carrier signal with wavelength of 193.1-THz from ECL1 possessing a power of 10-dBm, a linewidth of 0.1 MHz and an initial phase of 0 degree can be first modulated by 40-Gb/s hybrid 64/16/4QAM electrical radio frequency (RF) OFDM signal plotted in the inset of **Figure 3** into the corresponding modulated optical baseband OFDM signal in the RF to optical up-converter (RTO), which a polarization controller to split optical carrier signal into two branches, two parallel LiNb Mach-Zehnder Modulators (MZM) operated at null bias point provided with an extinction ratio (ER) of 60-dB, a bias voltage of 4v, and a insertion loss of 1dB to transform the in-phase and quadrature-phase electrical OFDM signal into in-phase and quadrature optical OFDM signal with the help of the upper branch and lower branch optical carrier, a phase shifter with 90 degree phase shift to add a time phase advance/delay to the input optical signal, and an optical coupler to recombine the two branches OOFDM signal into one branch, then coupled by a coupler to integrate the hybrid 64/16/4-QAM modulated OOFDM baseband signal and the optical signal with 193.2-THz wavelength from ECL2 into the mixing optical signal , and finally magnified by an EDFA operating at gain control mode owning gain and noise figure (NF) are 10- and 4-dB,respectively. The generated hybrid frequency signal is successfully launched into 20-km SSMF, which has attenuation factor of

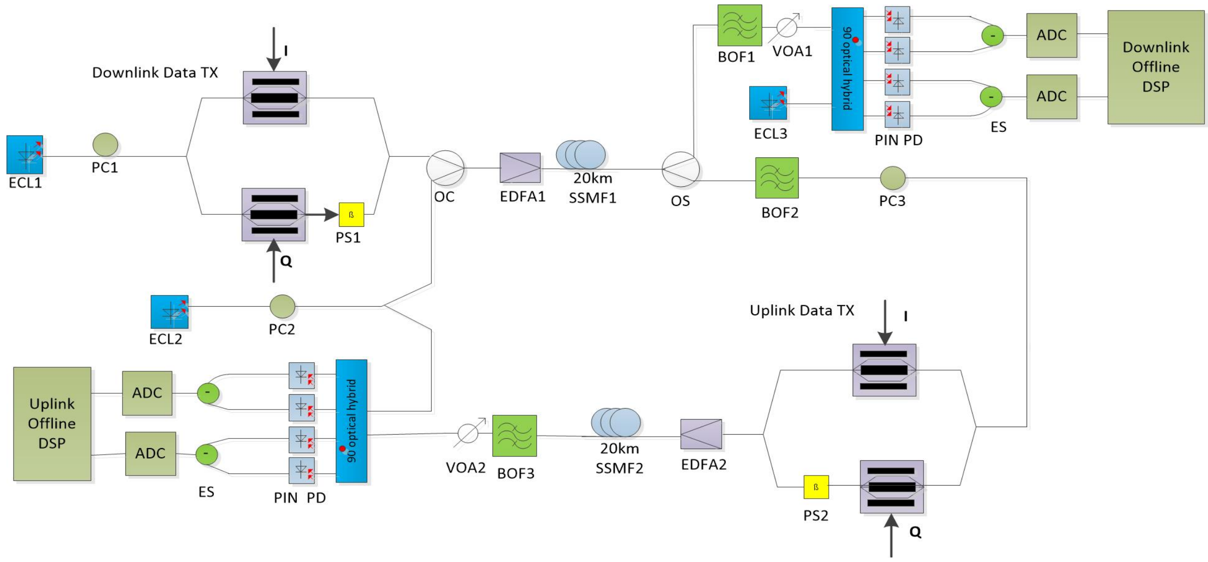


Figure 3. Experimental setup for the full-duplex OFDM-PON.

0.2-dB/km, chromatic dispersion (CD) coefficient of 16.7-ps/nm/km and polarization mode dispersion (PMD) coefficient of 0.05-ps/sqrt (km) and constant effective area data type. Subsequently, a passive optical splitter (POS) is adopted to divide the received optical signal into two branches signals.

At the base station (BS), one branch signal is first launched into Bessel optical filter with (BOF) with center frequency of 193.1-THz, 3-dB bandwidth of 40 GHz, and filter order of 3.Then, in order to change received optical power of the ONUs, it is highly desirable that the variable optical attenuator (VOA) between BOF1 and coherent detection is as simple as possible. Afterwards, the received signal is coherent detected with the local oscillator (LO) signal from ECL3 with the center frequency the same as that of the ECL1 in the coherent detector in the form of homodyne detection, which a 90 degree optical hybrid to use coherent signal demodulation and make two input signal into four output signal , four parallel PIN Photodiodes with responsivity of 1-A/W, modulation bandwidth 2-GHz, and sample rate of 40-GHz to transform the optical signal into electrical signal , two parallel electrical sub-tractor to subtract the four electrical signal into in-phase signal and quadrature signal, two parallel electrical amplifier (EA) with additive thermal noise (ATN) to promote the amplitude of the electrical signal. Finally, it should be mentioned that offline DSP in the OFDM demodulation, which concluding analog to digital conversion (ADC) accomplished by down-sampling to the global symbol rate, dispersion compensation implemented by digital filter, removing cyclical prefix (CP) to reduce the ISI and ICI, FFT to transform the discrete time domain signal into the discrete frequency domain signal, training symbols-based channel estimation, pilot symbols-based carrier phase estimation.

For uplink part, optical carrier signal after BOF2 with center frequency different from that after BOF1 is first modulated with the generated RF hybrid 16/8/QPSK OFDM electrical signal at the BS, which has the same functions as the downlink I/Q modulation. In order to match the launched optical power (LOP) transmitted over the exactly same SSMF used for downlink, the perfect combination of both EDFA2 and VOA2 can be used to bridge the power penalty between the transmitter and the receiver to achieve high system performance. On the other hand, at the receiver side, functioned as optical carrier signal from ECL1 has been coherently detected with the hybrid modulation optical baseband signal. From the perspective of the SSMF deployed from the BS to the CS, the situation of B2B is independent of 20-km fiber transmission. Finally, offline DSP has been experimentally investigated to implement OFDM demodulation.

4. Simulation Results and Discussion

As **Figure 4** demonstrates the optical spectrum of different location in this scheme, the optical spectrum before OC is shown in **Figure 4(a)**, which explains the transmission signal with power of 25-dBm and bandwidth of 10 GHz. **Figure 4(b)** illustrates the optical spectrum after OC, where both 100-GHz frequency spacing and 30-dBm power difference exist in modulated optical baseband signal at 193.1-THz and LO signal at 193.2-THz. The

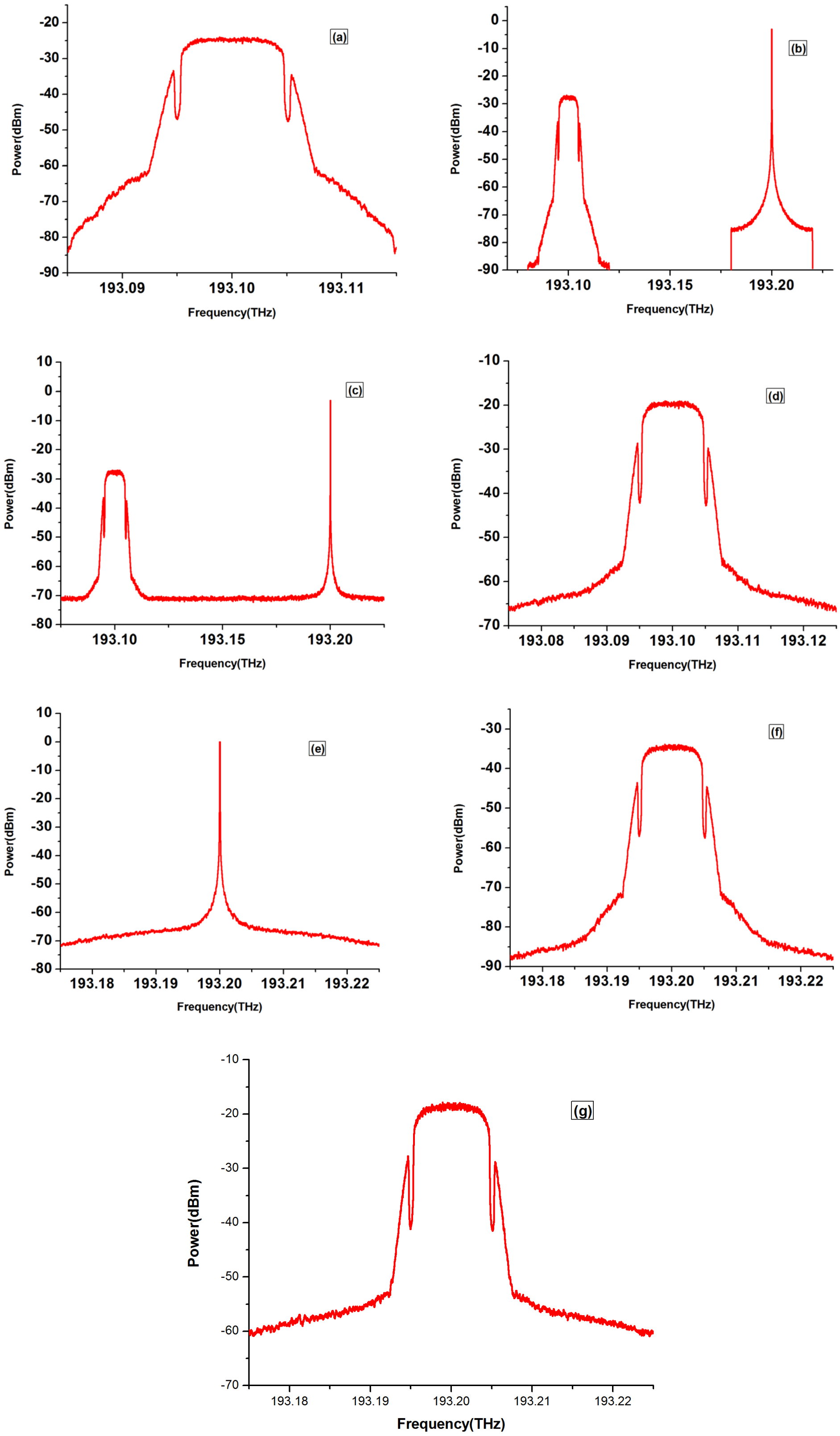


Figure 4. Optical spectra after: (a) In-phase/quadrature at the OLT; (b) OC at the OLT; (c) OS at the ODN; (d) BOF1 at the ONU; (e) BOF2 at the ONU; (f) In-phase/quadrature at the ONU; (g) BOF3 at the OLT.

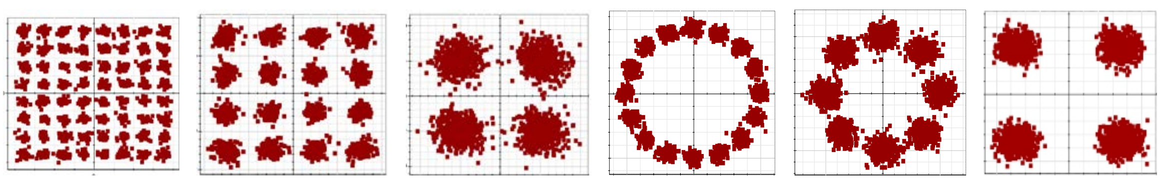
optical spectrum after 20-km SSMF transmission and OS is studied in **Figure 4(c)**, because of EDFA, the two signals is commendably connected. Afterwards, the optical spectrum after BOF1 and BOF2 are successfully depicted in **Figure 4(d)** and **Figure 4(e)**, respectively. **Figure 4(f)** presents the optical spectrum after in-phase/quadrature modulation for uplink part. The optical spectrum after BOF3 is gave in **Figure 4(g)**, which has bandwidth of 10 GHz more than power of 20 dBm.

Figure 5 indicates the constellation diagrams after carrier phase estimation based on pilot symbols for both downlink and uplink. The constellation diagrams of 64/16/4QAM OFDM signal are experimentally measured at the received optical power of −11.89-dBm, −24.11-dBm, and −34.12-dBm, namely, log of BER are about −3.19, −3.18, and −3.05, respectively, meanwhile, they are −15.78-dBm, −18.97-dBm, and −20.47-dBm for 16/8/QPSK OFDM signal, namely, log of BER are about −3.38, −3.22, and −3.15, respectively. It can be concluded from **Figure 5** that MPSK is more sensitive to phase shift than MQAM, where the original transmitted data have been well recovered after channel estimation and the bit error between before and after carrier phase estimation can be basically eliminated in the modulation scheme.

As can be seen in **Figure 6**, the relationship between the surveying BER and the ROP for downstream and upstream in 40-Gb/s coherent detection system is experimentally measured in this pollution highlighted in **Figure 6(a)** and **Figure 6(b)**, respectively. In addition, the net sequence length for hybrid 64/16/4QAM OFDM are 15360, 10240, and 5120, respectively, at the same time, they are 5120, 7680, and 10240 for hybrid QPSK/8PSK/16PSK OFDM, respectively. For a specific BER, log of BER is −3, the receiver sensitivity of 64/16/4QAM-OFDM signal are about −13.5, −24.5, and −34-dBm, respectively, meanwhile, 16/8/QPSK-OFDM signal for uplink transmission are about −16, −19.5, and −21-dBm, respectively.

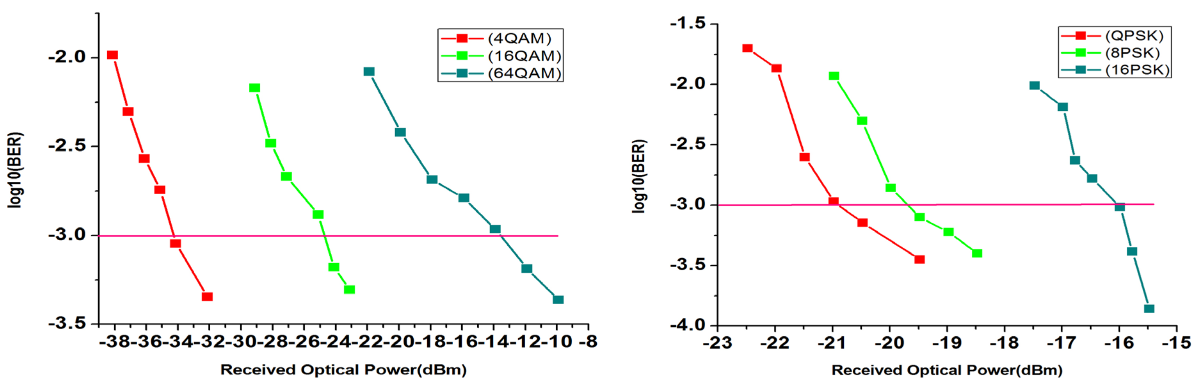
5. Conclusion

A 40-Gb/s full-duplex PON infrastructure has been successfully propose and simulation demonstrate over 20km SSMF, which be significantly characterized as both hybrid modulation 64/16/4QAM OFDM signal for the downlink and hybrid modulation 16/8/Q-PSK OFDM signal for the uplink, remaining the inherent advantages introduced by orthogonal, high IFFT/FFT size, high-level QAM (MQAM) and coherent detection. Because ODN is free source, signal coming from different modulation technique can be independently transceiver for both downstream and upstream.



(a) (b) (c) (d) (e) (f)

Figure 5. Constellation diagrams before after CPE for (a) 64QAM; (b) 16QAM; (c) 4QAM; (d) 16PSK; (e) 8PSK; (f) QPSK.



(a) (b)

Figure 6. Measured BER of (a) downstream and (b) upstream signals versus received optical power.

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